JC07 Rec'd PCT/PTO 30 APR 2001

FORM PTO-1390 (REV. 11-2000) U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		2360-0340P
		U.S. APPLICATION NO. (If known, see 37 CFR 1.5) 09/830687
INTERNATIONAL APPLICATION NO.	**INTERNATIONAL FILING DATE**	**PRIORITY DATE CLAIMED**
PCT/CH99/00509	October 29, 1999	October 30, 1998

TITLE OF INVENTION

EQUALIZATION METHOD ESPECIALLY FOR OFFSET MODULATION MODES

APPLICANT(S) FOR DO/EO/US

ALDIS, James

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39 (1).
4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. ☒ is transmitted herewith (required only if not transmitted by the International Bureau). WO 00/27083
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is transmitted herewith.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4)
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3)).
   a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ An English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 20. below concern document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98-1449 w/ 3 documents
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment.
14. ☐ A SECOND or SUBSEQUENT preliminary amendment.
15. ☐ A substitute specification.
16. ☐ A change of power of attorney and/or address letter.
17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821-1.825.
18. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. ☒ Other items or information:
    1.) Translation of Annexes to International Prelimnary Examination Report w/ Verification of Translation
    2.) Verification of Translation for Specification
    3.) Three (3) sheets of Formal Drawings

JC08 Rec'd PCT/PTO 30 APR 2001

U.S. APPLICATION NO (if known, see 37 CFR 1.5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
09/830687	PCT/CH99/00509	2360-0340P

				CALCULATIONS	PTO USE ONLY
21. ☒ The following fees are submitted: **BASIC NATIONAL FEE (37 CFR 1.492(a)(1)-(5):** Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO. . . . . **$1,000.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO . . . . **$860.00** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO. . . . . **$710.00** International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) . . . . **$690.00** International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4). **$100.00**					
ENTER APPROPRIATE BASIC FEE AMOUNT =				$ 1000.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				$ 130.00	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total Claims	4 - 20 =	0	X **$18.00**	$ 0	
Independent Claims	4 - 3 =	1	X **$80.00**	$ 80.00	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)		None	+ **$270.00**	$ 0	
TOTAL OF ABOVE CALCULATIONS =				$ 1210.00	
☒ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.				$ -605.00	
SUBTOTAL =				$ 605.00	
Processing fee of **$130.00** for furnishing the English translation later than ☐20 ☐30 months from the earliest claimed priority date (37 CFR 1.492(f)). +				$ 0	
TOTAL NATIONAL FEE =				$ 605.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$ 0	
TOTAL FEES ENCLOSED =				$ 605.00	
				Amount to be: refunded	$
				charged	$

a. ☒ A check in the amount of $ 605.00 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account. No. ___________ in the amount of $_______ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 02-2448.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

Send all correspondence to:

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Date: April 30, 2001

By [signature]
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/cqc

IN THE U.S. PATENT AND TRADEMARK OFFICE

Applicant:	ALDIS, James	Conf.:	
Int'l. Appl. No.:	PCT/CH99/00509		
Appl. No.:	New	Group:	
Filed:	April 30, 2001	Examiner:	
For:	EQUALIZATION METHOD ESPECIALLY FOR OFFSET MODULATION MODES		

PRELIMINARY AMENDMENT

BOX PATENT APPLICATION
Assistant Commissioner for Patents
Washington, DC 20231

April 30, 2001

Sir:

The following Preliminary Amendments and Remarks are respectfully submitted in connection with the above-identified application.

AMENDMENTS

IN THE SPECIFICATION:

Please amend the specification as follows:

Before line 1, insert --This application is the national phase under 35 U.S.C. § 371 of PCT International Application No. PCT/CH99/00509 which has an International filing date of October 29, 1999, which designated the United States of America and was not published in English.

Docket No. 2360-0340P

REMARKS

The specification has been amended to provide a cross-reference to the previously filed International Application.

If necessary, the Commissioner is hereby authorized in this, concurrent, and future replies, to charge payment or credit any overpayment to Deposit Account No. 02-2448 for any additional fees required under 37 C.F.R. § 1.16 or under 37 C.F.R. § 1.17; particularly, extension of time fees.

Respectfully submitted,

BIRCH, STEWART, KOLASCH & BIRCH, LLP

By ______________________
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2360-0340P

(Rev. 02/12/01)

09/830687

Method for equalizing a received signal

Technical field

The invention relates to a method for equalizing a received signal in a digital receiver with the aid of a DFE (Decision Feedback Equalizer) structure, the received signal being based on a signal constellation which is one-dimensional or can be transformed to be one-dimensional.

Prior art

The transmition channels typically occurring in the case of GSM (Global System for Mobile Communication), HIPERLAN (High PErformance Radio Local Area Netzwork), DECT (Data Exchange for Cordless Telephone) etc. are characterized by the interfering effects of multipath propagation.

It is known that a Decision Feedback Equalizer (DFE) can be used in order to equalize in the digital communication system a signal which has been disturbed by a linear frequency-selected process (such as the multipath propagation in a radio channel, for example).

The performance of a DFE depends on the quality with which the filter coefficients are calculated and/or fixed in the feedforward part and in the feedback part. In the case of an unknown channel, the coefficients are typically fixed by adaptive training. If the pulse response of the channel is known, by contrast, the optimum coefficients of the DFE can then be derived therefrom.

The structure of a DFE is very simple per se and therefore very readily used. However, it is not always possible to achieve the desired performance.

Summary of the invention

The object of the invention is to specify a method of the type mentioned at the beginning which permits the determination of optimum coefficients with as little outlay on computation as possible on the

basis of the known and/or previously estimated channel unit pulse response, an enhanced performance being achieved at the same time by comparison with the known DFE in accordance with the prior art.

The features of Claim 1 define the achievement of the object. In accordance with the invention, the coefficient of the DFE are fixed so as to minimize the expected value of the squared real part of the error.

By contrast with the prior art, the error, which is a complex value per se, is not used as a basis for optimization. However, calculation is limited to the real value. The filter coefficients of the feedback filter are not complex, only those of the feedforward filter being so in general. The essential point is that the performance of the DFE structure can be improved in this basically simple way, it even being possible to reduce the computational outlay in comparison with the prior art.

In the case of a binary BPSK signal the coefficients are preferably calculated in accordance with the formulas (I) and (II) specified further below.

The invention is suitable not only for BPSK (BPSI [sic] = Binary Phase Shift Keying) signals, but also for GMSK and OQPSK modulation methods (GMSK = Gaussian Minimum Shift Keying, OQPSK = Offset Quadrature Phase Shift Keying). Also to be regarded as one-dimensional modulation methods are, therefore, those which although having a two-dimensional signal constellation can be transformed (with the aid of a suitable transformation) into an (at least approximately) equivalent one-dimensional represent-ation.

The circuitry for implementing the method according to the invention poses no special difficulties. The calculation is typically programmed in a processor or ASIC.

The invention is suitable, for example, for a HIPERLAN system. (Such an advantageous system structure follows, for example, from EP 0 795 976 A2, Ascom Tech

AG). The so-called European Telecommunications Standard (ETS) defines the technical characteristics of a wireless local high performance network (HIPERLAN). HIPERLAN is a short range communications subsystem with a high data rate (compare in this regard ETSI 1995, ETS 300 652, UDC: 621 396). The ETS-HIPERLAN standard is provided for the frequency band 5.15 to 5.30 GHz.

Further advantageous embodiments and combinations of features of the invention result from the following detailed description and the totality of the patent claims.

Brief description of the drawings

In the drawings used to explain the exemplary embodiment:

Figure 1 shows a diagrammatic illustration of a DFE;

Figure 2 shows a diagrammatic illustration of an exemplary embodiment;

Figure 3 shows a representation of the performance of the method according to the invention by comparison with the prior art;

Figures 4a-c show a comparison of the error behavior in the prior art and with the invention;

Figure 5 shows a diagrammatic illustration of a BPSK receiver;

Figure 6 shows a diagrammatic illustration of a GMSK receiver.

Ways of implementing the invention

The principle of the invention is to be stated below by a comparison with the prior art.

Figure 1 shows a block structure, known per se, of a DFE. The received signal I downwardly modulated by the carrier is entered into a feedforward filter FF of the DFE. Thereafter, it is combined (adder) with the estimated signal $\hat{I}$ fed back by the decision devide DD via the feedback filter FB. The signal $\tilde{I}$ is therefore

present at the input of the decision device DD. The coefficients **f** and **g** (which are understood in the present as vectors with a plurality of coefficient components) are calculated as follows in accordance with the prior art:

$$\min_{f,g} E\left\{\left|\tilde{I}-\hat{I}\right|^2\right\} \qquad \text{(A)}$$

In contrast therewith, the invention carries out the following optimization:

$$\min_{f,g} E\left\{\left(\mathrm{Re}\left(\tilde{I}-\hat{I}\right)\right)^2\right\} \qquad \text{(B)}$$

The difference from the prior art therefore consists in the type of calculation of the filter coefficients. The remaining structure of the DFE is maintained without change. This is explained in detail below with the aid of exemplary embodiments.

Figure 2 shows a concrete example of a DFE. As is usual for modern coherent digital receivers, the signal processed by it is represented by complex numbers. The real part stands in this case for the in phase component, and the imaginary part stands for the quadrature component. In accordance with the generally current understanding, the DFE shown in Figure 2 has complex coefficients and complex data.

If only the real part of the error is optimized according to the MMSE (MMSE = Minimum Mean Square Error) criterion, the feedforward filter coefficients are given by the following system of equations:

$$\text{(I)} \qquad h^R_{M+1-i} = \frac{\sigma^2}{2} f_i^R + \sum_{m=1}^{M} f_m^R \sum_{n=1}^{M} h^R_{n+1-i} h^R_{n+1-m} - \sum_{m=1}^{M} f_m^I \sum_{n=1}^{M} h^R_{n+1-i} h^I_{n+1-m}$$

$$-h^I_{M+1-i} = \frac{\sigma^2}{2} f_i^I - \sum_{m=1}^{M} f_m^R \sum_{n=1}^{M} h^I_{n+1-i} h^R_{n+1-m} + \sum_{m=1}^{M} f_m^I \sum_{n=1}^{M} h^I_{n+1-i} h^I_{n+1-m}$$

These are 2M real equations $(1 \le i \le M)$. Coefficients whose indices are too great or too small are to be taken as 0 in this case. The indices run from 1 to L for vectors of length L. The values of the filter coefficients can be obtained using methods known per se for solving systems of linear equations. There is no need to go into these standard methods in more detail.

The feedback filter coefficients are determined by the following equations:

$$\text{(II)} \qquad g^R_{i-M} = -\sum_{m=1}^{M} f^R_m h^R_{i+1-m} - f^I_m h^I_{i+1-m}$$

These are N-1 equations, because $M + 1 \le i \le M + N - 1$.

Formulae (I) and (II) are based on the following conventions:

- N length of the channel unit pulse response;
- M length of the feedforward filter;
- h_1^R real part of the channel unit pulse response, $1 \le i \le N$,
- h_1^I imaginary part of the channel unit pulse response, $1 \le i \le N$,
- f_1^R real part of the filter coefficients of the feedforward part of the DFE, $1 \le i \le M$,
- f_1^I imaginary part of the filter coefficients of the feedforward part of the DFE, $1 \le i \le M$,
- g_1^R real part of the filter coefficients of the feedforward part of the DFE, $1 \le i \le N-1$,
- σ^2 noise power at the input of the DFE (real part and imaginary part of the noise power combined). If this value is not known, it can be set to be constant without substantially reducing the performance.

Mostly, M = N. It is no advantage to have N < M. The complexity can be reduced at the expense of the performance if N > M. However, the calculation

according to the invention nevertheless supplies the optimum filter coefficients with reference to the mean quadratic error.

The length of the feedback filter is equal to or one shorter than the length of the channel unit pulse response (that is to say $\tilde{N}-1$). Were the length selected to be larger, the coefficients of the additional taps would all be 0. A shorter length would lead to intersymbol interference at the input of the decision device. Because the addition of taps to the feedback filter does not substantially increase the overall complexity, the full length is used as a rule.

The coefficients of the feedback filter have no imaginary part. The reason for this is that the input to the feedback filter is real, as is its output. (The imaginary part of the input of the decision device is not considered.)

The calculation according to the invention of the filter coefficients is suitable for different applications. It is shown below how the performance of a HIPERLAN receiver can be improved. In this case, the known complex MMSE method is contrasted with the real MMSE method according to the invention. It is presupposed, furthermore, that the receivers carry out a 3-antenna selection diversity. Simulation of the appropriate receivers permits the packet error rate to be estimated.

It is assumed that the parameter σ^2 lies 10 dB and [sic] the received signal power in the receiver. Furthermore, the starting point is radio channels with a delay spread of 45 ns or 75 ns. The DFE has a 8 feedforward taps and 7 feedback tabs.

The results displayed in Figure 3 show a significant improvement in both applications of the calculating method according to the invention. The error rate is higher for large delay spreads (75 ns). Error rates below the threshold of measureability are established at 20 dB signal-to-noise and 45 ns delay spread.

The effect of the method according to the invention can be illustrated with the aid of Figures 4a to 4c. If QPSK [sic] is used as modulation method, the decision device outputs one of the four complex values 1 + j, 1 - j, -1 + j, -1 - j as a function of which of them comes closest to the input value of the decision device. The input value is distorted by the noise and the non-eliminated residual intersymbol interference. This is expressed in Figures 4a-c by the cloud-like distributions.

The minimization of the complex quadratic error leads to a distribution resembling a circular disk around each constellation point, as is shown in Figures 4a and 4b. By contrast therewith, the minimization according to the invention of the real part of the quadratic errors leads to an oval distribution (Figure 4c) which is, as it were, squashed. Viewed in the complex plain, the mean value of the (complex) quadratic error is greater than in the case of the prior art (Figures 4a, b). However, the error is shifted onto the imaginary axis. On the real axis, it is smaller than in the case of the prior art. However, since the output of the decision device can only be real, the increased error plays no role on the imaginary axis.

Figure 5 shows how the invention is integrated in a BPSK receiver. The data 1 are modulated onto a carrier wave in a transmitter by a BPSK modulator 2. In a receiver, a demodulator 3 ensures the received signal is converted into the frequency baseband, and ensures the appropriate filtering. Thereafter, the signal is sampled at the symbol rate (sampler 4). The output of the sampler is processed by the channel estimator 5, on the one hand, and by the DFE 7, on the other hand. The calculation of the coefficients in accordance with the invention takes place in the coefficient computer 6. The transmitted data 8 are present at the output of the DFE 7. The structure of the receiver is known per se. What is new is the way described further above in which

the coefficients are determined in the coefficient computer 6.

Fundamentally, the invention can also be used for a QPSK [sic] method (the modulators/demodulators requiring to be appropriately designed). By contrast with the BPSK receiver, it is then necessary for the DFE to operate in each case with complex numbers.

The general layout of the GMSK transmission method is shown in Figure 6. The data 9 are precoded in a known way on the transmitter side in a precoder 10 and modulated onto a carrier way with the aid of a GMSK modulator 11. A demodulator 12 in a receiver ensures conversion of the received signal into the frequency baseband, and ensures appropriate filtering. Thereafter, the signal is sampled (sampler 13) at the symbol rate. The output of the sampler is multiplied by a phase factor j^i (phase shifter 14, multiplier 15) and thereafter processed by the channel estimator 16, on the one hand, and by the DFE 18, on the other hand. The calculation of the coefficients takes place according to the invention in the coefficient computer 17. The transmitted data 19 are present at the output of the DFE 18. Here, as well, the structure of the receiver is known per se. What is new is the way in which the coefficients are determined in the coefficient computer 6.

The aim below is to explain how the invention can be used for GMSK and OQPSK modulation methods, which seem at first glance to have a two-dimensional signal constallation.

It is known that the GMSK modulated signal represented in the complex baseband can be specified as follows by a binary bit stream with the symbols $b_k \in [-1, +1]$, $k = \ldots -1, 0, 1, 2 \ldots$:

$$\text{(III)} \qquad s_u(t) = A \exp\left[\frac{j\pi}{2}\sum_k b_k \int_{-\infty}^{t-kT} g(\tau)d\tau + \phi_0\right]$$

A and ϕ_0 denote the amplitude and the initial carrier phase; $g(\tau)$ is the (Gaussian partial response) pulse, which defines the phase modulation, and T is the symbol or bit duration.

The modulated signal can be approximated effectively by the following linear partial response QAM signal, as a function of the pulse $g(\tau)$:

$$\text{(IV)} \qquad \tilde{s}_0(t) = A\exp(j\phi_0)\sum_k \alpha_k \tilde{g}(t-kT)$$

In this case, the terms α_k are complex data symbols which depend only on the symbols b_k and have the value range [+ 1, -1, + j, -j]. $\tilde{g}(t)$ is a partial-response pulse shaping function. It holds that:

$$\text{(V)} \qquad \alpha_k = \exp\left(\frac{j\pi}{2}\sum_{n=-\infty}^{k} b_n\right)$$

It is known (Baier, A. et al., "Bit Synchromization and Timing sensitivity in Adaptive Viterbi Equalizers for Narrowband-TDMA Digital Mobile Radio Systems", IEEE 1988, CH 2622-9/9/0000-0377] that the above approximation can be very good for GMSK modulation with the aid of a time/bandwidth product of 0.3 as used in GSM and HIPERLAN.

This approximation corresponds precisely to a linear QAM modulation with the aid of data symbols from the value range [+1, -1, +j, -j]. The sum

$$\sum_{n=-\infty}^{k} b_n$$

is alternately even and odd, so that transmitted symbols α_k are alternately real and imaginary. This modulation is known under the designation of OQPSK (offset quadrature phase shift keying). The transition

between the symbols α_k and b_k is very simple. It may be pointed out that the transition from α_k to b_k is robust against errors, whereas it is not so for the inverse transition. A single error in the sequence b_k will entail very many (possibly infinitely many) errors in the derived sequence of the symbols α_k.

The transmitted symbols α_k must be recovered in the receiver. It is assumed below that the same frame synchronization is available in the transmitter and in the receiver. It is known of the first symbol α_0 that it is real (specifically either +1 or -1). If the first symbol is imaginary, a slight adaptation of the subsequent formalism is required. The transmitted signal is $\tilde{s}_0(t)$ and the received signal is r(t), which constitutes a convolution with the channel unit pulse response and the analog filters of the receiver:

$$\text{(VI)} \qquad r(t) = A\sum_k \alpha_k h(t-kT)$$

h(t) being the convolution of the transmission signal with $g^{\sim}(t)$, the initial phase shift, the channel unit pulse response and the pulse response of the totality of the filters on the receiver side.

The complex baseband signal is sampled in the receiver in accordance with the channel symbol rate so as to generate a time-discrete signal. This can be described as follows:

$$\text{(VII)} \qquad \tilde{r}_i = A\sum_k \alpha_k h(iT+\lambda-kT)$$

A sampling phase λ was adopted. $\lambda=0$ can be set without limitation of generality, because a time delay can always be included in the channel unit pulse response.

The signal is multiplied by the phase j^{-i} before being fed to the DFE:

$$\breve{r}_i = j^{-i} A \sum_k a_k h(iT - kT)$$

$$\text{(VIII)} \quad \breve{r}_i = A \sum_k j^{-k} a_k j^{-(i-k)} h((i-k)T)$$

$$\breve{r}_i = \sum_k c_k h((i-k)T)$$

c_k is the data sequence derived from a_k. Note that the phase j^{-i} can assume only the values [+1, -1, +j, -j]. It is therefore very easy to multiply that [sic] received signal by this phase (compare multiplier 14 in Figure 6).

$$\text{(IX)} \quad c_k = j^{-k}\alpha_k = \exp\left(\frac{-jk\pi}{2}\right)\exp\left(\frac{j\pi}{2}\sum_{n=-\infty}^{k} b_n\right) = \exp\left(\frac{j\pi}{2}\left(-k + \sum_{n=-\infty}^{k} b_n\right)\right) \in \left\{ \begin{matrix} \{-1,+1\} & \alpha_n \in \Re \\ \{-j,+j\} & \alpha_n \in \Im \end{matrix} \right.$$

One of these cases can be avoided if a frame synchronization is available. The second possibility is therefore ignored. It can therefore be detected that the signal values sampled on the receiver side is [sic] a convolution of the exclusively real data sequence c_k with the specific function $\breve{h}(t)$ which includes:

- the pulse shaping of the modulation,
- the channel unit pulse response,
- the initial phase of the carrier signal,
- the time offset of the sampling, and
- the rotation with the phase j^{-i} in the receiver.

The function can be determined, for example, with the aid of a training sequence and a correlation calculation in the receiver. This is the function which is used in the receiver to calculate the filter coefficients of the DFE. The DFE must generate only a real output, because the basic data are exclusively real (c_k). Finally, it is possible (given knowledge of the index k) to determine the original data symbols α_k.

As mentioned further above, the GMSK modulation can be approximated very well by the OQPSK modulation (with the precondition that the time/bandwidth product

is known and the transformation of the data stream is performed between α_k and b_k). It is possible in this way to use the DFE according to the invention for GMSK and OQPSK as well. Only one additional, but simple and robust transformation of the data is required. An additional simplification is achieved if precoding is used in the transmitter before the GMSK modulation.

Given an unfavorable time/bandwidth product, the equalizing of GMSK in a way according to the invention can lead to a slightly worse performance than in the case of OQPSK, because despite everything GMSK is not exactly linear after the data transformation. However, the instances of worsening can be neglected if the time/bandwidth product is of the usual order of magnitude.

It may be stated in summary that it is possible to improve the equalization with the aid of the invention in the case of the in practice very greatly widespread one-dimensional modulation methods and with the use of the advantageous DFB structure. The evaluation in the feedback filter can be performed using real values instead of complex ones. Again, the output of the feedforward filter need only be real. Consequently, all that need be carried out in this filter is those calculations which contribute to the real value of the output. Receivers according to the invention can, for example, be used in the case of GSM telephones or cordless DECT telephone sets, or in the case of data communication between computers on the basis of HIPERLAN.

Patent Claims

1. Method for equalizing a received signal in a digital receiver with the aid of a DFE (Decision Feedback Equalizer) structure, the received signal being based on a signal constellation which is one-dimensional or can be transformed to be one-dimensional, characterized in that the coefficients of the DFE are fixed so as to minimize the expected value of the squared real part of the error in the received signal.

2. Method according to Claim 1, characterized in that the signal constellation corresponds to a BPSK modulation, and in that the coefficients of the DFE are fixed as follows:

$$\text{(I)}\quad h^R_{M+1-i} = \frac{\sigma^2}{2} f_i^R + \sum_{m=1}^{M} f_m^R \sum_{n=1}^{M} h^R_{n+1-i} h^R_{n+1-m} - \sum_{m=1}^{M} f_m^I \sum_{n=1}^{M} h^R_{n+1-i} h^I_{n+1-m}$$

$$-h^I_{M+1-i} = \frac{\sigma^2}{2} f_i^I - \sum_{m=1}^{M} f_m^R \sum_{n=1}^{M} h^I_{n+1-i} h^R_{n+1-m} + \sum_{m=1}^{M} f_m^I \sum_{n=1}^{M} h^I_{n+1-i} h^I_{n+1-m}$$

$$\text{(II)}\quad g^R_{i-M} = -\sum_{m=1}^{M} f_m^R h^R_{i+1-m} - f_m^I h^I_{i+1-m}$$

3. Method according to Claim 1, characterized in that the signal constellation corresponds to a GMSK or an OQPSK modulation, and in that the samples are rotated in the receiver with a phase j^{-i}, i denoting a sequential index of the sample.

4. Circuit arrangement of a DFE (Decision Feedback Equalizer) for equalizing a received signal in a digital receiver, the received signal being based on a signal constellation which is one-dimensional or can be transformed to be one-dimensional, characterized in that [lacuna] a circuit for calculating the coefficients of the DFE in such a way that the expected

value of the squared real part of the error in the received signal is a minimum.

Abstract

The invention relates to a method for equalizing a received signal in a digital receiver with the aid of a DFB [sic] (Decision Feedback Equalizer) structure. The received signal is based on a signal constellation (for example BPSK, GMSK, OQPSK) which is one-dimensional or can be transformed to be one-dimensional. The coefficients of the DFE are fixed so as to minimize the expected value of the squared real part of the error in the received signal. In contrast with the prior art, the error, which is a complex value per se, is not used as a basis for optimization. However, calculation is limited to the real value. Instead of being complex, the filter coefficients can also be real. The essential point is that the performance of the DFE structure can be improved in this basically simple way, it even being possible to reduce the computational outlay by comparison with the prior art.

(Figure 4c)

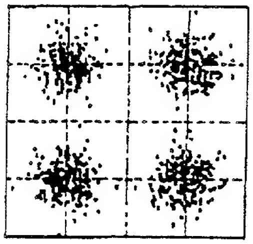

Fig.4a

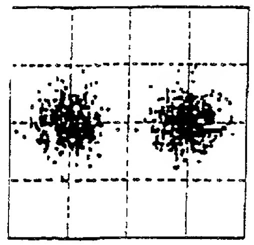

Fig.4b

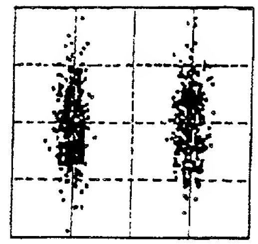

Fig.4c

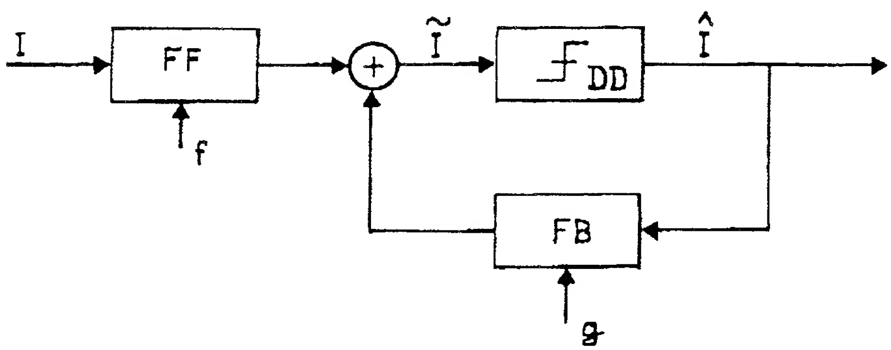

Fig.1

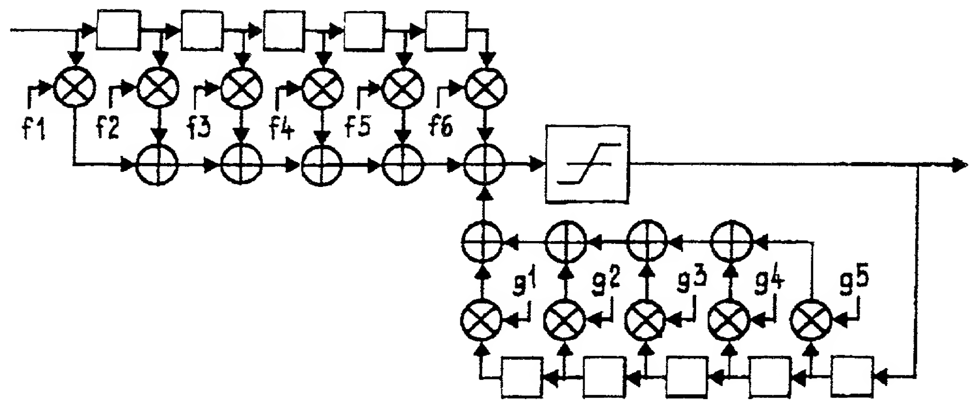
f1
f2
f3
f4
f5
f6
g1
g2
g3
g4
g5

Fig. 2

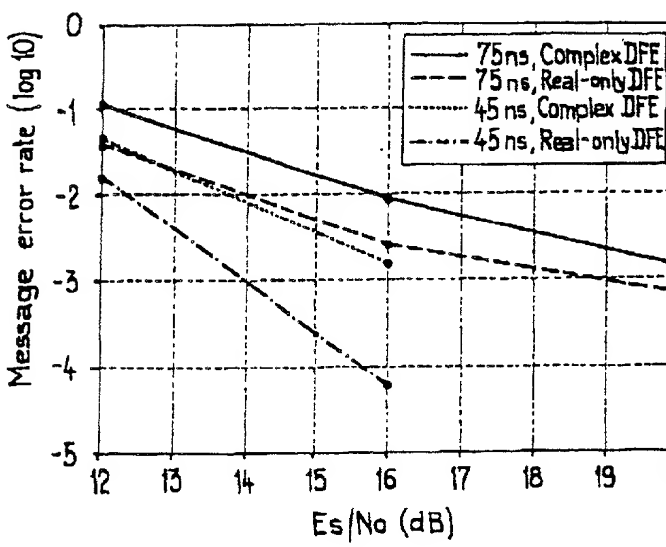
Message error rate (log 10)
0
-1
-2
-3
-4
-5
12
13
14
15
16
17
18
19
20
Es/No (dB)
75ns, Complex DFE
75 ns, Real-only DFE
45 ns, Complex DFE
45 ns, Real-only DFE

Fig. 3

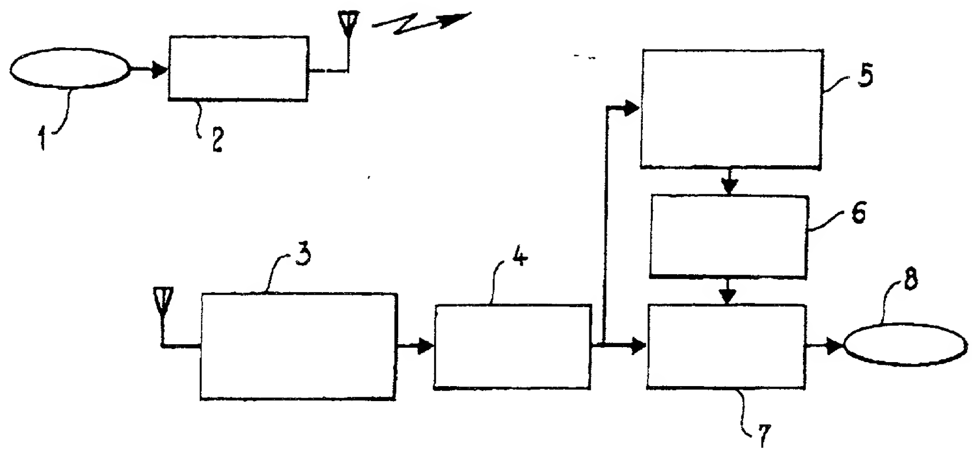

Fig.5

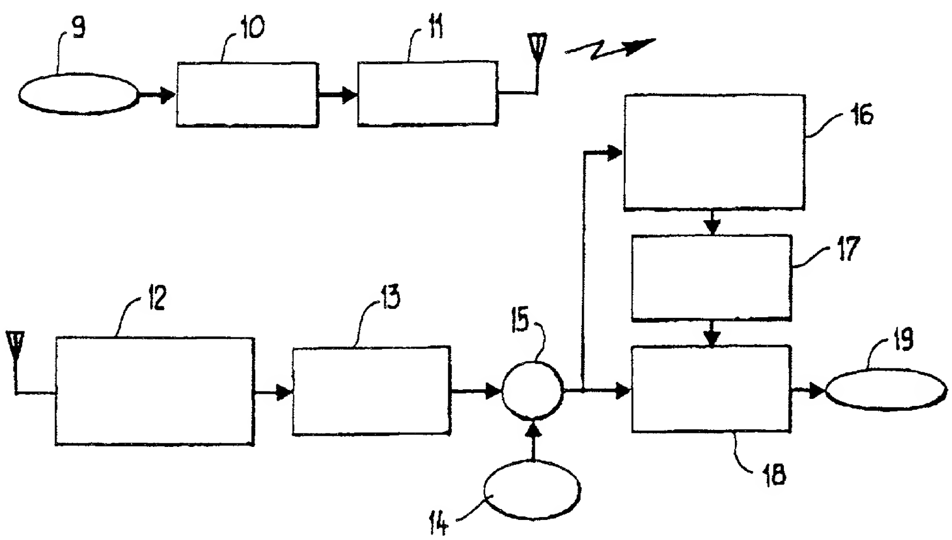

Fig.6

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I hereby appoint the following attorneys to prosecute this application and/or an international application based on this application and to transact all business in the Patent and Trademark Office connected therewith and in connection with the resulting patent based on instructions received from the entity who first sent the application papers to the attorneys identified below, unless the inventor(s) or assignee provides said attorneys with a written notice to the contrary:

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1-00

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full Name of First or Sole Inventor: Insert Name of Inventor; Insert Date This Document is Signed →

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Residence (City, State & Country)		CITIZENSHIP
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*DATE OF SIGNATURE

1U622

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PLEASE NOTE: YOU MUST COMPLETE THE FOLLOWING

COMBINED DECLARATION AND POWER OF ATTORNEY FOR PATENT AND DESIGN APPLICATIONS

As a below named inventor, I hereby declare that: my residence, post office address and citizenship are as stated next to my name; that I verily believe that I am the original, first and sole inventor (if only one inventor is named below) or an original, first and joint inventor (if plural inventors are named below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

Insert Title: EQUALIZATION METHOD ESPECIALLY FOR OFFSET MODULATION MODES

Fill in Appropriate Information - For Use Without Specification Attached:

the specification of which is attached hereto. If not attached hereto,
the specification was filed on ______ as
United States Application Number ______;
and amended on ______ (if applicable) and/or
the specification was filed on ______ as PCT
International Application Number PCT/CH99/00509; and was
amended under PCT Article 19 on ______ (if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

I do not know and do not believe the same was ever known or used in the United States of America before my or our invention thereof, or patented or described in any printed publication in any country before my or our invention thereof or more than one year prior to this application, that the same was not in public use or on sale in the United States of America more than one year prior to this application, that the invention has not been patented or made the subject of an inventor's certificate issued before the date of this application in any country foreign to the United States of America on an application filed by me or my legal representative or assigns more than twelve months (six months for designs) prior to this application, and that no application for patent or inventor's certificate on this invention has been filed in any country foreign to the United States of America prior to this application by me or my legal representatives or assigns, except as follows.

I hereby claim foreign priority benefits under Title 35, United States Code, §119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Insert Priority Information: (if appropriate)

Prior Foreign Application(s)			Priority Claimed	
98 811 090.4 (Number)	Europe (Country)	October 30, 1998 (Month/Day/Year Filed)	☒ Yes	☐ No
(Number)	(Country)	(Month/Day/Year Filed)	☐ Yes	☐ No
(Number)	(Country)	(Month/Day/Year Filed)	☐ Yes	☐ No
(Number)	(Country)	(Month/Day/Year Filed)	☐ Yes	☐ No

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional applications(s) listed below.

Insert Provisional Application(s): (if any)

(Application Number)	(Filing Date)
(Application Number)	(Filing Date)

All Foreign Applications, if any, for any Patent or Inventor's Certificate Filed More than 12 Months (6 Months for Designs) Prior to the Filing Date of This Application:

Insert Requested Information: (if appropriate)

Country	Application Number	Date of Filing (Month/Day/Year)

I hereby claim the benefit under Title 35, United States Code, §120 of any United States and/or PCT application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States and/or PCT application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to the patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

Insert Prior U.S. Application(s): (if any)

(Application Number)	(Filing Date)	(Status - patented, pending, abandoned)
(Application Number)	(Filing Date)	(Status - patented, pending, abandoned)